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FY05 HAST EVALUATION REPORT

Prepared by: Naval Surface Warfare Center, Crane Division
Component Engineering Branch, Code 6056

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Executive Summary

This report summarizes the results of an extensive HAST evaluation of plastic encapsulated microcircuits (PEMs) involving multiple manufacturers of similar device types in the same IC package. The purpose of this evaluation was to gain some insight on the following questions:

- Are apparent delaminated areas of PEMs critically significant?
- Are manufacturers assigning the appropriate moisture sensitivity levels (MSL)?
- Has overall PEM construction quality and reliability improved?
- Does PEM quality and reliability still vary from lot to lot and manufacturer to manufacturer?

The data acquired from this evaluation was compared to historical data obtained from similar evaluations performed in the early 1990's and later. These particular devices are equivalent device types and IC package types to those commonly used in many military systems in the mid 1990's. The evaluated devices are listed in Table 1 and the test flows are shown in Figure 1.

Table 1 Evaluated PEMs

MANUFACTURER	COMMERCIAL P/N	PACKAGE TYPE	COMMENTS
Integrated Device Technologies (IDT)	IDT74FCT244CTSO	SOIC	Level 1 preconditioning
Integrated Device Technologies (IDT)	IDT74FCT244CTSO	SOIC	Level 3 preconditioning
Fairchild (FSC)	74ABT244C	SOIC	Level 1 preconditioning
Fairchild (FSC)	74ACTQ244SC	SOIC	Level 1 preconditioning
Fairchild (FSC)	74ACT244SC	SOIC	Level 1 preconditioning
Fairchild (FSC)	74ACT244SC	SOIC	Level 3 preconditioning
Motorola (MT)	74ACT244	SOIC	Level 1 preconditioning
Motorola (MT)	74ACT244	SOIC	Level 3 preconditioning
Texas Instruments (TI)	74ACT244	SOIC	Level 1 preconditioning
Texas Instruments (TI)	74ACT244	SOIC	Level 3 preconditioning

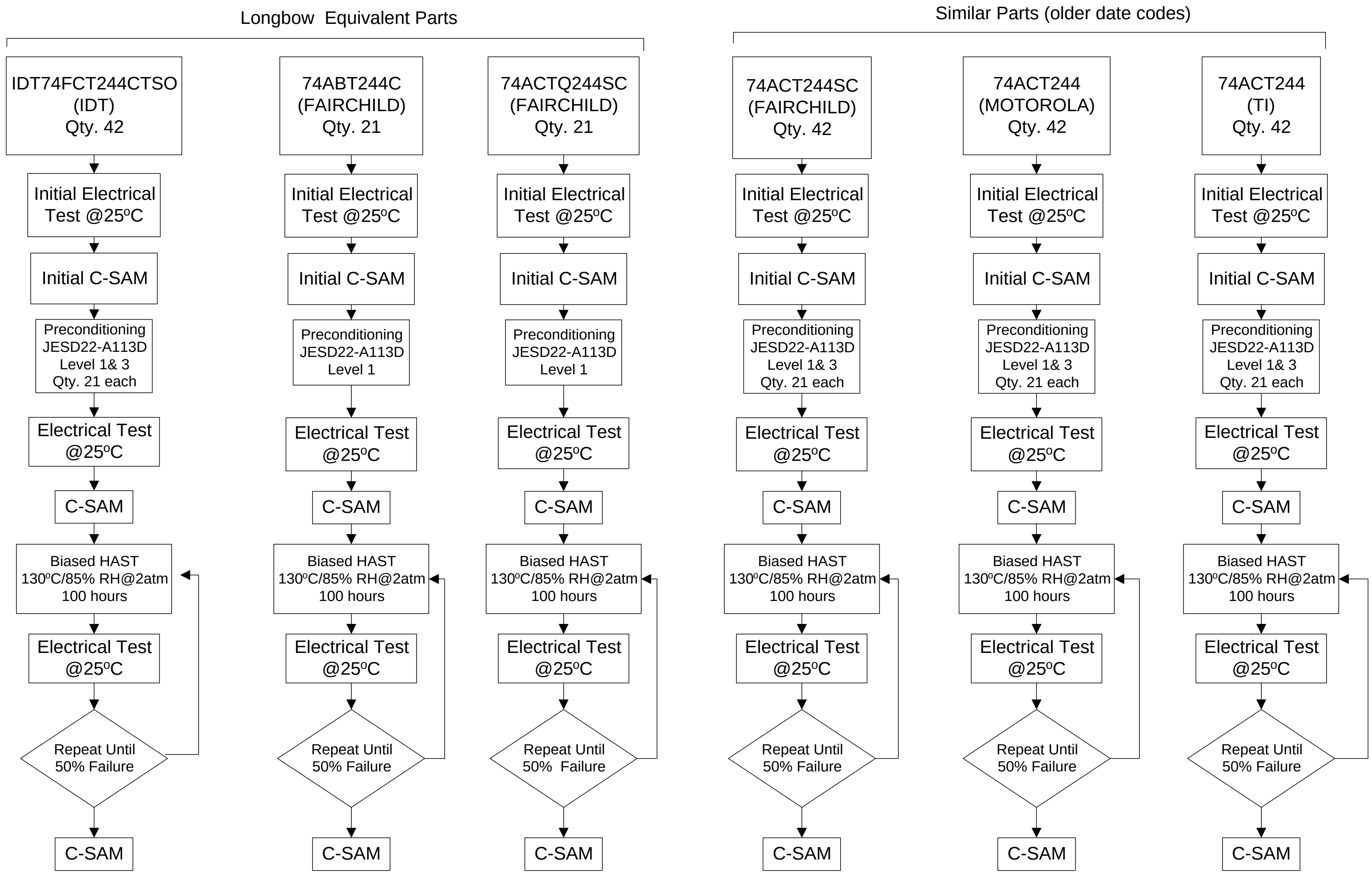

Figure 1 HAST Evaluation Test Flow

The evaluation followed the test flow in Figure 1. If enough devices were available, two preconditioning sequences were performed on that device type in order to see the impact that the different levels had on the HAST results. Figure 2 gives a visual representation, using C-SAM, of the different affects that level 1 and level 3 preconditioning sequences have on the IDT74FCT244CTSO devices. The yellow areas in the bottom images are suspected delaminated areas. These suspect areas were of interest for the HAST evaluation. These areas if they were delaminated they could allow moisture to collect and potentially accelerate a corrosive reaction if impurities were present in the epoxy molding compound.

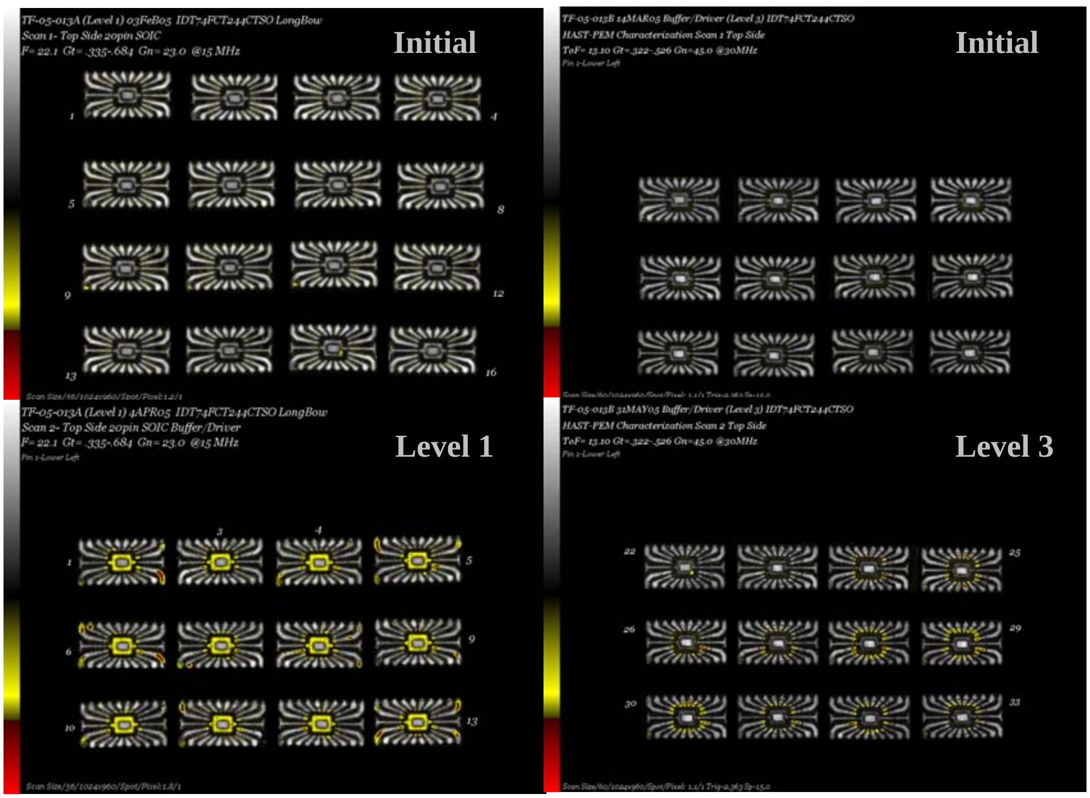

Figure 2 C-SAM Images of Devices Subjected to Level 1 and Level 3 Preconditioning

Figure 3 illustrates the HAST evaluation results. The desired 50% failure rate could not be attained in this evaluation because of lead integrity problems that made electrical contact almost impossible. The HAST evaluation ran for a total of 1300 hours. PEM HAST performance was manufacturer dependent. The preconditioning level had an inconsistent impact on the HAST results. HAST is a tool that will determine if materials' incompatibilities are present within a device. This evaluation proved that manufacturers have more finely tuned their recipe for epoxy molding compounds. No earth shattering results were exhibited from this evaluation. The results from this evaluation were somewhat better than the previous evaluation.

As far as determining true PEM reliability or life, HAST will not do it. HAST is one piece of the puzzle. PEM quality and reliability will always be manufacturer dependent. If at all possible, there should be manufacturer choices for any device. A simple evaluation test flow as outlined in Figure 1 along with an initial DPA and post HAST DPA is a cost effective means for manufacturer selection, determining the appropriate MSL and risk assessment for any PEM.

Background

Highly Accelerated Stress Test (HAST) has been an accepted method of evaluating PEM reliability. The typical failure mechanism of PEMs , traditionally, has been Kirkendall voiding caused by the impurities in the epoxy molding compound. HAST has the ability to accelerate this phenomenon. Over time it has been proven by HAST testing that epoxy molding compounds contain less impurities but, overall, has PEM construction quality and reliability improved? One aspect that has always been in question concerning HAST testing is the exposure time. JEDEC standard JESD22-A110-B, "Highly-Accelerated Temperature and Humidity Stress Test (HAST)", recommends the exposure time of 96 hours at 130^{o}C/85%RH @ 2atm of pressure. There have been debates on whether or not this is an adequate amount of exposure time. This evaluation will extend that exposure time until 50% failure rate has been achieved.

Prior to any HAST testing, each component will be subjected to a preconditioning sequence following JESD22-A113D to simulate a solder reflow process. Solder reflow is the harshest stress that a device will be subjected to. The preconditioning sequence is representative of the manufacturer's rated moisture sensitivity level (MSL). Questions and concerns have arisen in regards to the manufacturers not rating their product with the appropriate MSL. For this reason if an ample number of devices were available for a given part type, these devices were subjected to two different preconditioning sequences. The preconditioning sequences were level 1 and level 3. Level 1 being the most aggressive. The question is " Will the varying preconditioning sequences impact the HAST results?" The C-SAM (Scanning Acoustic Microscopy) results in Figure 2 illustrate the impact that the different preconditioning sequences have on the same devices. If devices do exhibit delaminated areas, are these areas critically significant as far as reliability is concerned?

One of the main drivers of PEM quality and reliability has been the manufacturer. This evaluation involves four manufacturers. Is PEM reliability still manufacturer dependent?

These are some questions that this evaluation will entertain.

Test Results

The HAST evaluation was initially scheduled to proceed until there was a 50% failure rate for each device type. The 50% failure rate could not be achieved. Only 1300 hours of HAST could be completed because of electrical continuity problems due to the integrity of the device leads. Test results for this evaluation are illustrated in Figure 3. Figure 4 incorporates the results from this evaluation with historical results. The HAST

results were somewhat better than the previous evaluation, thus proving that the epoxy molding compounds have less impurities and contaminants. PEM reliability appears to be most greatly influenced by the manufacturer. This fact has been proven by this evaluation as well as previous evaluations. The preconditioning level was also a variable in this evaluation. The results were inconsistent between the level 1 and level 3 preconditioning sequences. The C-SAM results indicated that the devices subjected to level 1 preconditioning exhibited more anomalies than the level 3 devices but these anomalies had no consistent impact on the HAST results. The first failure was exhibited by a Motorola 74ACT244 (level 1) device. The failure occurred after 200 hours of HAST. The failure mode was the typical Kirkendall voiding (purple plague) as illustrated in the gold ball bond cross section in Figure 5. No more failures occurred on this test lot through the remaining exposure time of HAST. The same device subjected to level 3 preconditioning exhibited no failures after 1300 hours.

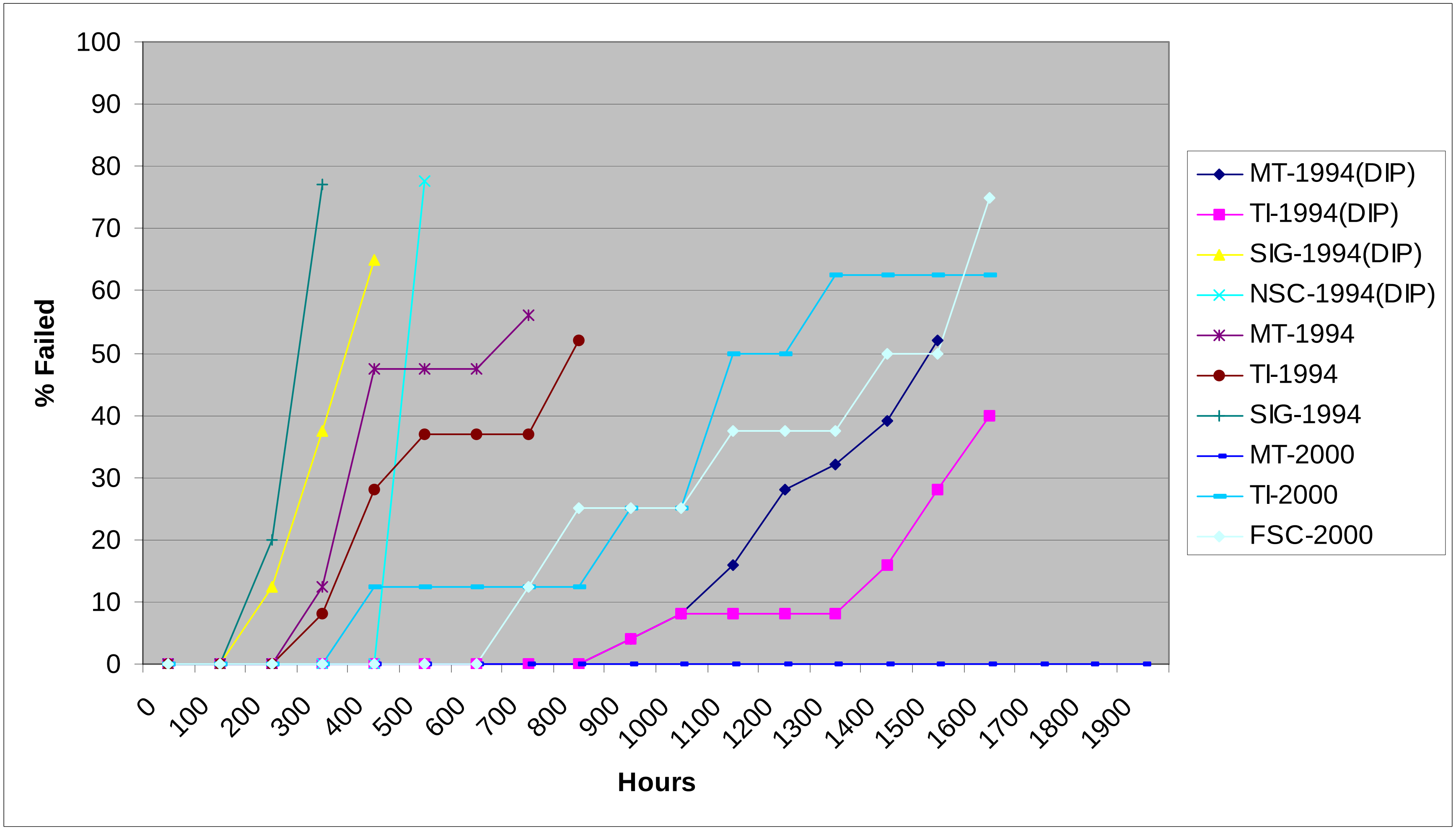

Figure 3 Current HAST Evaluation Results

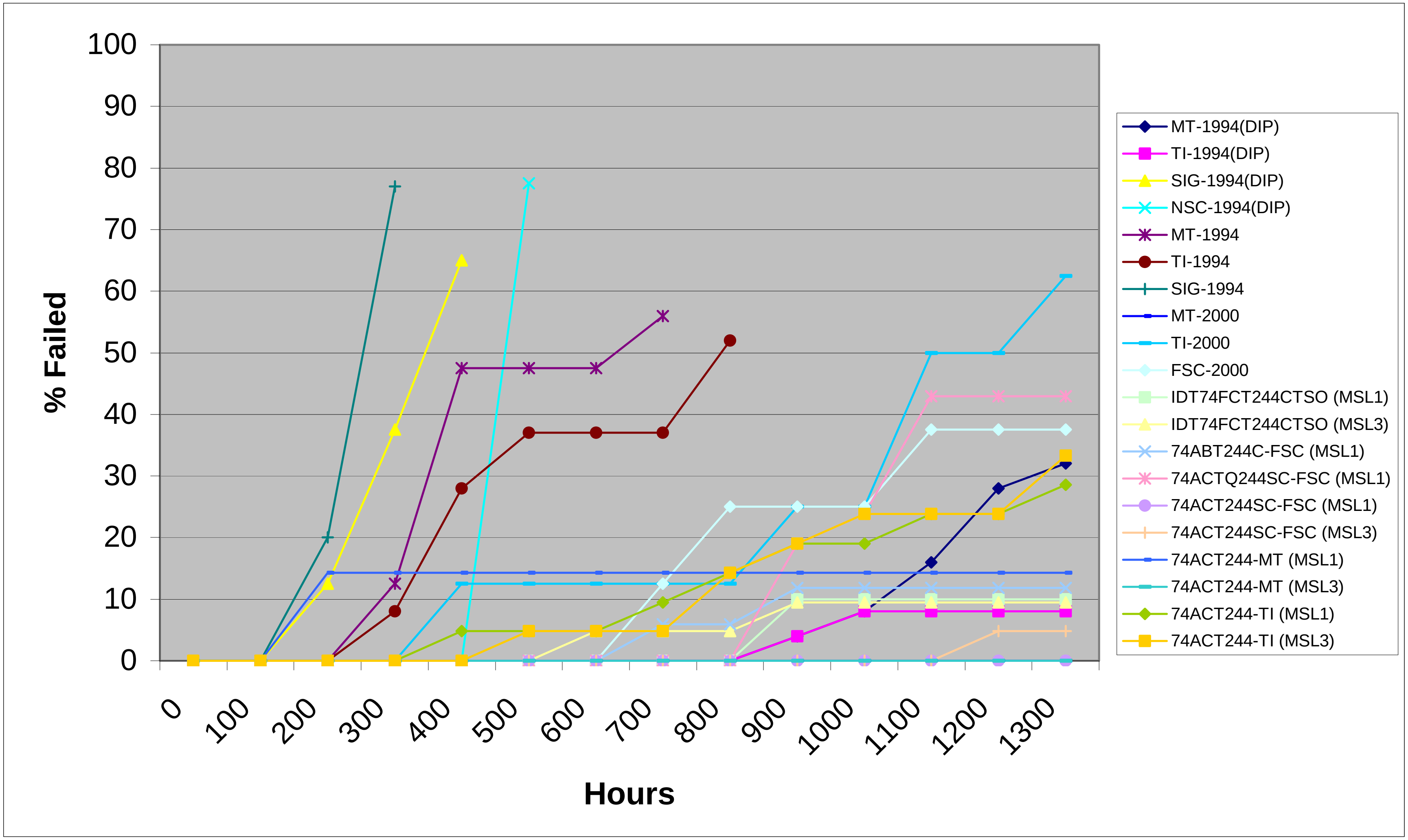

Figure 4 Current/Historical HAST Evaluation Results

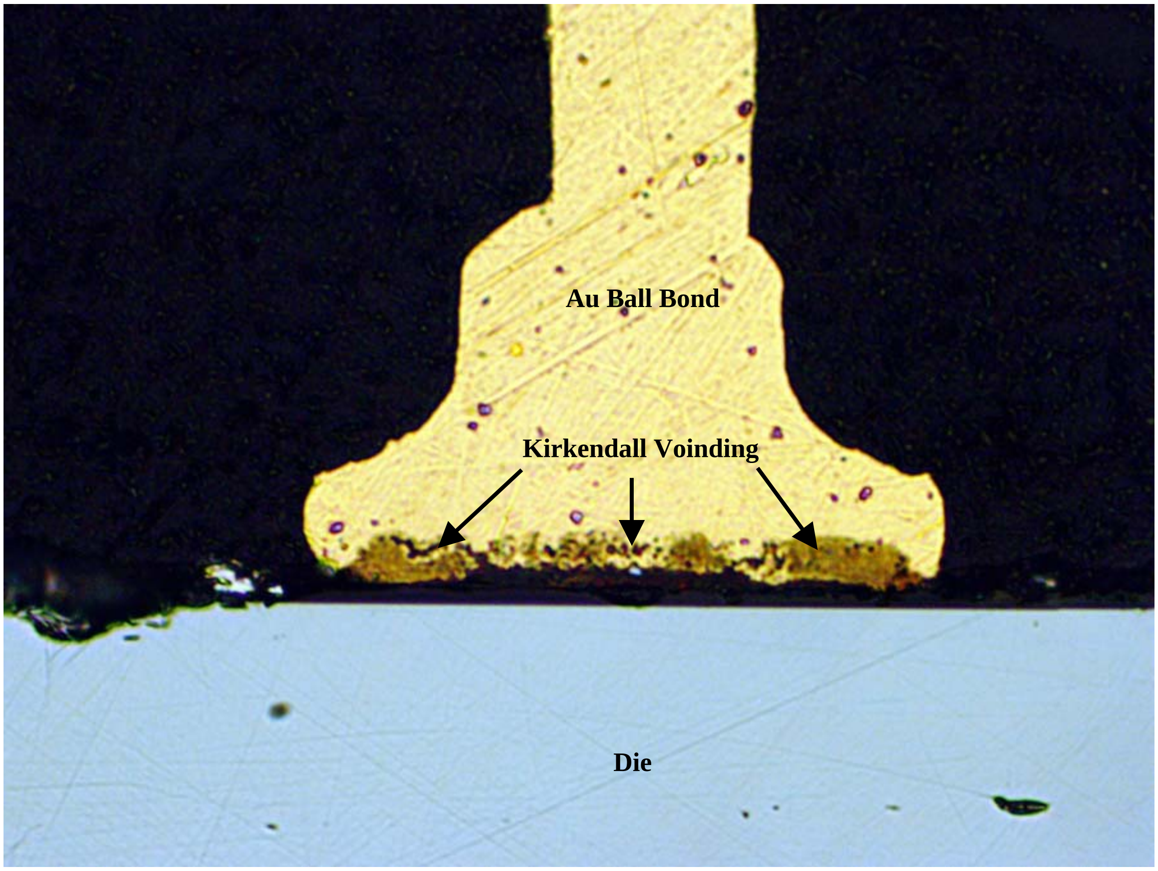

Figure 5 Cross Section of Au Wire Ball Bond with Kirkendall Voiding

Conclusions/Recommendations

The main mission of this HAST evaluation was to determine if overall PEM construction quality and reliability has improved. HAST alone can not complete this mission. The HAST test flow in Figure 1 will help determine if there are materials' incompatibilities present in PEMs and with the preconditioning sequence will help to verify if the appropriate MSL has been assigned by the manufacturer.

The correct manufacturer MSL designation is critical for PEM reliability and its longest possible life. There has been evidence to suggest that manufacturers are not assigning the appropriate MSL for certain IC packages.

In a recent study conducted by the Component Engineering Branch of NSWC Crane a voltage regulator in a TO-220 package was supplied by three manufacturers with different MSL designations. Two of the manufacturers designated their devices as a level 3 and one a level 1. All of the devices supplied by the three manufacturers were divided into separate test lots and subjected to level 1 and level 3 preconditioning sequences to investigate this peculiarity. Devices subject to level 1 preconditioning exhibited anomalous areas in C-SAM analysis whereas the level 3 devices exhibited nothing. These areas were verified by destructive physical analysis as delaminations at various

material interfaces depending upon what type of die attach was used. The level 3 rating should be the recommended choice.

The question arises, “Are these delaminated areas critically significant?” Figures 6, 7, and 8 illustrate the typical material interfaces that delaminate. These interfaces include the die attach-header interface, the die attach-die interface, the die- epoxy molding compound interface, and the header-epoxy molding compound interface. The interfaces involving the die attach are of particular interest. The die attach interface is a means of thermal conductivity and/or electrical connectivity. There are guidelines available for acceptance criteria (percent defect) for C-SAM inspection of die attach in MIL-STD-883G method 2030. Delaminated areas involving the die attach interfaces are significant. The delaminated interface involving the top of the die and the epoxy molding is also significant. Figure 8 illustrates this interface. A thermal cycling environment could cause potential problems in promoting a shearing action against the ball bond. This shearing action could cause the bond to fatigue prematurely thereby creating intermittent continuity problems. If this delaminated area extends across the top of the die, there is a high probability that moisture could collect on top of the die. This collected moisture could pose a threat of corrosion. I know, “Why didn’t this corrosive reaction occur during HAST testing?” HAST testing uses distilled/deionized water. There is not one military environment that pure water will be the only element involved. There will be contaminants in that moisture that the epoxy molding compound will absorb. Metal corrosion could always be a possibility. If there is such a thing as a least critical delaminated interface, it would be between the header and the epoxy molding compound. Although this interface is not critical for the functionality of a device, it is a good indicator of the quality of the manufacturing process.

An incorrect manufacturer MSL designation can also lead to catastrophic results. A FPGA packaged in a 208 pin PQFP was evaluated following the test flow in Figure 1. The manufacturer MSL rating was level 3. After the preconditioning sequence, an anomaly was exhibited in C-SAM analysis. Electrical testing after the HAST exposure resulted in failures in the area which had exhibited the C-SAM anomaly. Figure 9 illustrates the destructive physical analysis (DPA) findings. The interfaces had delaminated so bad in the suspect area that the wire ball bonds had cracked causing electrical failures. The DPA report concluded that the damage was done during the preconditioning sequence. The HAST exposure was purely a catalyst for the ensuing failures. This same device was then executed through the same test flow with the exception that the device was treated as if had a MSL 6 rating. The change made an impact on the results. C-SAM anomalies were still present but no electrical failures occurred after the test sequence.

When military systems were initially, more or less, forced to use PEMs because of the unavailability on MIL-SPEC hermetic devices on the market, PEM manufacturers still practiced MIL quality inspection points in their processes. The unknown was the epoxy molding compounds. HAST was an effective means of evaluating these epoxy molding compounds. Time appears to have reversed this. The epoxy molding compounds have gotten better but the manufacturing quality has regressed. It appears that the quality inspection points have been dropped possibly to lower costs. Figures 8-11 illustrate examples of this theory. Simple processes such as die placement and wire bonding can not be taken for granted. Die planarity problems, lack of die attach fillet and lack of die

attach in general are commonly seen problems. Instances of wire bond misregistration, none uniform ball bonds and silicon cratering are also commonplace. These are some examples of the process control issues.

"Has overall PEM construction quality and reliability improved?", probably not. PEM quality and reliability will always be manufacturer dependent. If at all possible, there should be manufacturer choices for any device. A simple evaluation test flow as outlined in Figure 1 along with an initial DPA and post HAST DPA is a cost effective means for manufacturer selection, determining the appropriate MSL and risk assessment for any PEM.

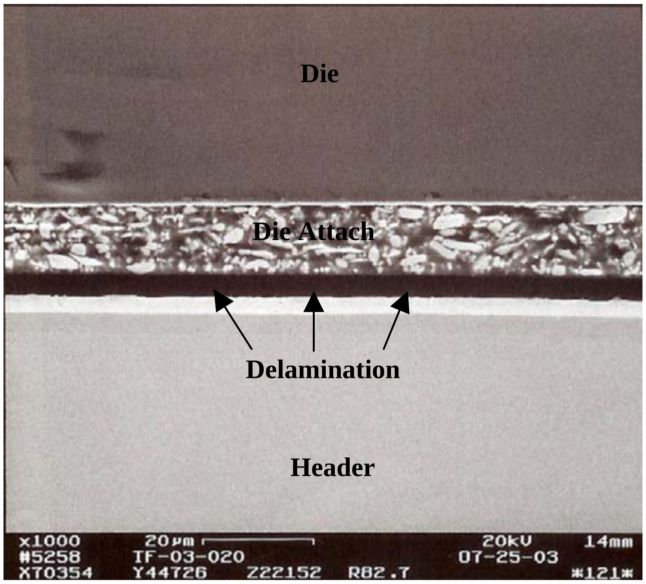

Figure 6 Cross Section of Delaminated Die Attach/Header Interface

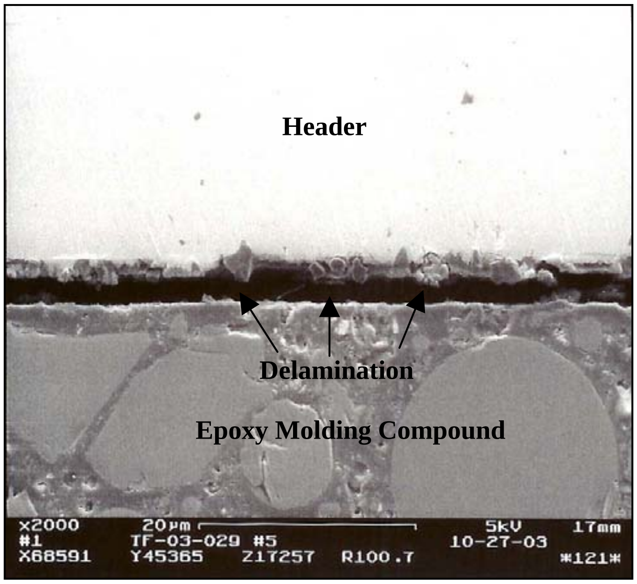

Figure 7 Cross Section of Delaminated Epoxy Molding Compound/Header Interface

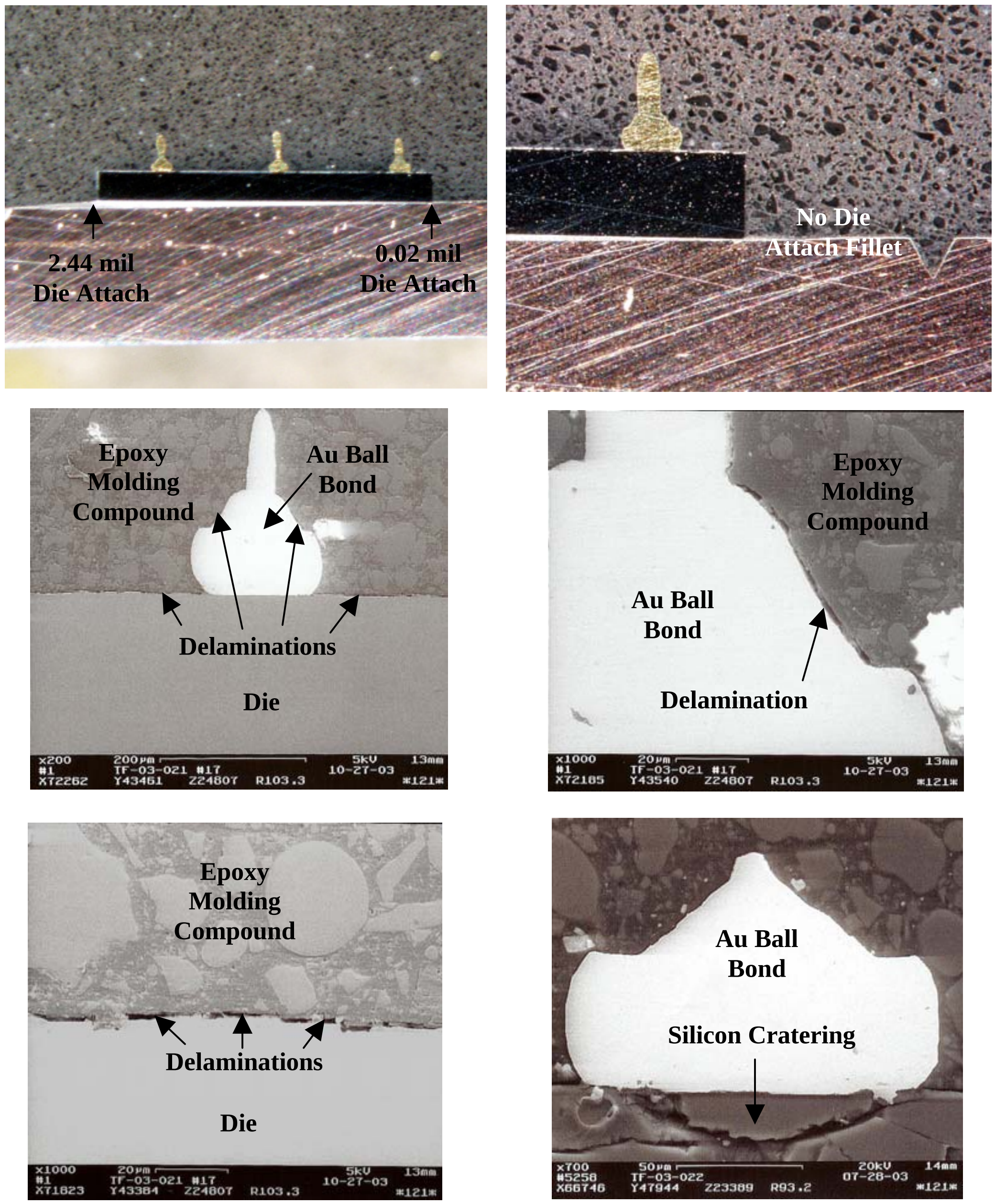

Figure 8 Physical Anomalies Exhibit by a Voltage Regulator in a TO-220 Package After Test Sequence

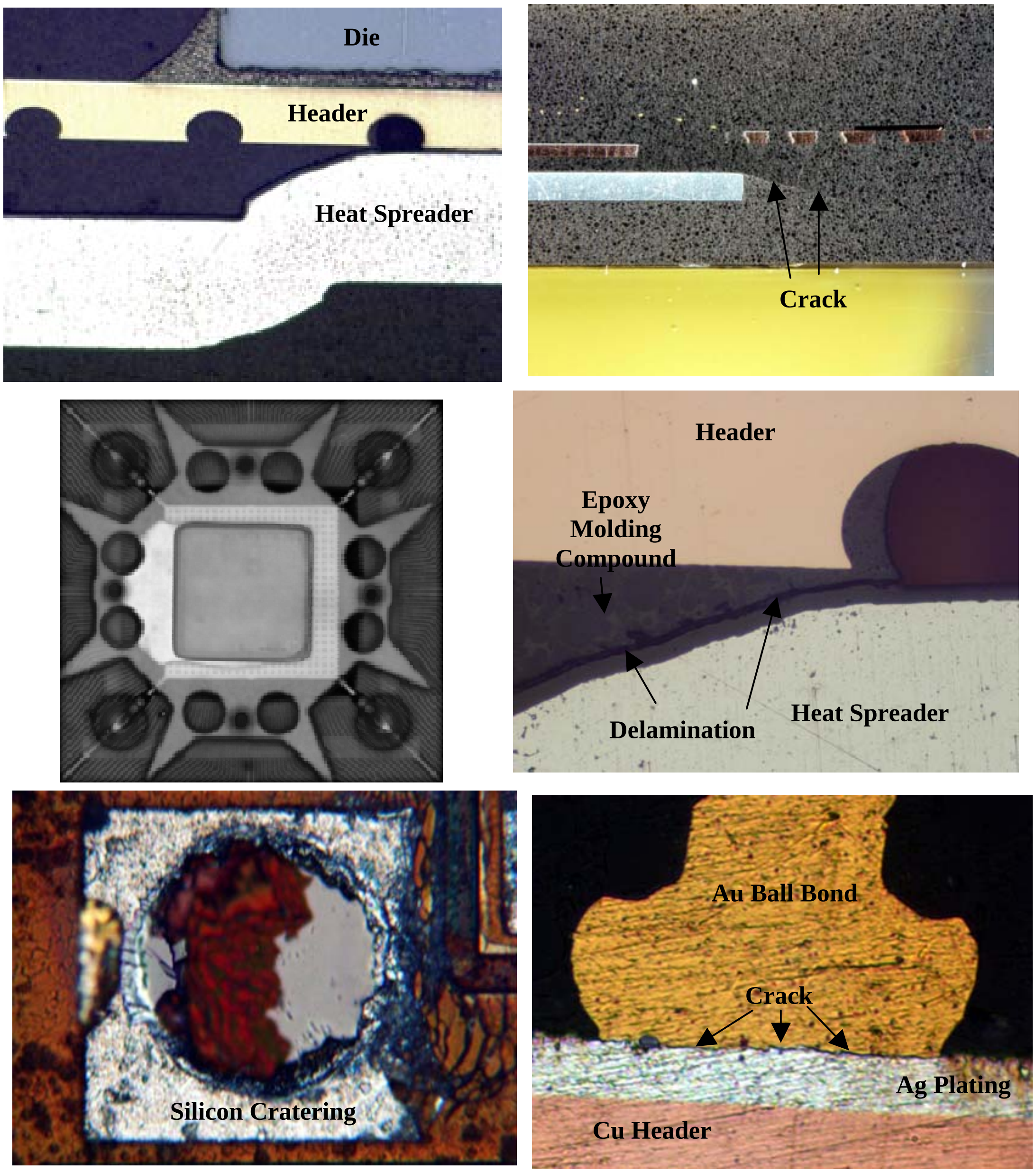

Figure 9 Physical Anomalies Exhibit by a FPGA Packaged in a 208 Pin PQFP After Test Sequence

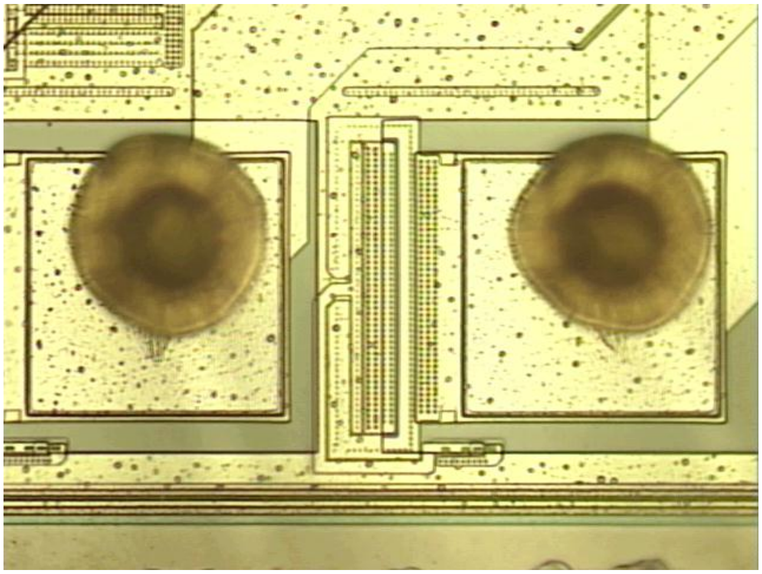

Figure 10 Minor Ball Bond Misregistration

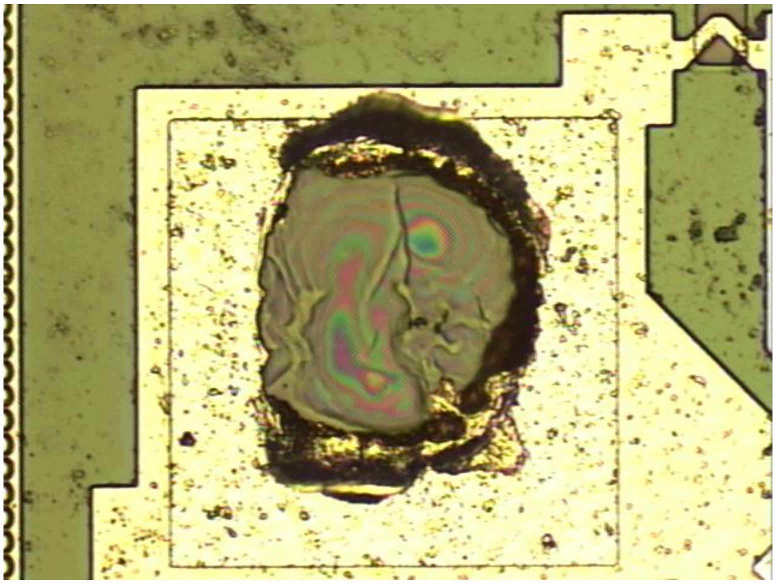

Figure 11 Silicon Cratering